Effects of Individual Differences on Operators' Interaction with Imperfect Automation in a Simulated Multitasking Environment

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ABSTRACT

We simulated a military tank environment and examined the performance of the combined position of gunner and robotics operator and how aided target recognition (AiTR) capabilities with imperfect reliability (i.e., miss-prone or false-alarm-prone) for the gunnery task might affect the concurrent robotics and communication tasks. Specifically, we investigated whether performance was affected by individual differences in attentional control and spatial ability. Results showed that when the robotics task was simply monitoring the video, participants had the best performance in their gunnery and communication tasks and the lowest perceived workload, compared with the other robotics tasking conditions. There was a strong interaction between the type of AiTR unreliability and participants' perceived attentional control. Overall, for participants with higher perceived attentional control, false-alarm-prone alerts were more detrimental; for low attentional control participants, conversely, miss-prone automation was more harmful. Consistent with previous findings, low spatial ability participants preferred visual cueing, and high spatial ability participants favored tactile cueing.

1.0 INTRODUCTION

In this study, we simulated a military tank environment and examined the performance of the combined position of gunner and robotics operator and how aided target recognition (AiTR) capabilities with imperfect reliability for the gunnery task might affect the concurrent robotics and communication tasks. Specifically, we investigated whether performance was affected by individual differences factors such as perceived attentional control (PAC) and spatial ability (SpA). We followed the paradigm of Chen and Terrence [1] and manipulated the reliability of the AiTR cueing system (i.e., false-alarm [FA] and miss rates). Based on the data from Wickens, Dixon, Goh, and Hammer [2], we expected that the operator's gunnery (automated) task performance would degrade if the FA rate of the AiTR for the gunnery system was high because of reduced compliance with the automation. Conversely, if the cueing was miss-prone (MP), the operator's robotics (concurrent) task performance would be affected more than the gunnery task because of reduced reliance on the automation. More mental and visual resources would be devoted to checking the raw data for the automated task, and therefore, the performance of the concurrent task would be degraded. On the other hand, there was evidence that FAP automation was more detrimental to both the automated and concurrent tasks than MP automation [3]. Therefore, it is likely that false-alarm-prone (FAP) automation would have a more negative impact on the overall performance than would MP automation. In other words, there have been conflicting results in the literature regarding the independence of the effects of FAP and MP automation on operator compliance and reliance. It is possible that individual differences may be responsible for some of the observed differences in the literature. Therefore, we investigated the effects of individual differences on FAP and MP conditions as a possible explanation for the discrepancies.

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14. ABSTRACT

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In the current study, we sought to investigate the effects of individual differences in SpA and PAC on the operators' concurrent performance. Several studies show that there are individual differences in multitasking performance, and some people are less prone to performance degradation during multitasking conditions [4][5]. There is some evidence that attention-switching flexibility can predict performance of such diverse tasks as flight training and bus driving [6]. There is also evidence that people with better attention control can allocate their attention more flexibly and effectively [7][8], and this was partially confirmed by Chen and Joyner [9]. It is likely that operators with different levels of attention switching abilities may react differently to automated systems with FAs and misses. In other words, operators' compliance and reliance behaviors may be altered based on their ability to effectively switch their attention among the systems. For example, the complacency effect may be more severe for poor attentional control individuals compared with those with better attentional control. The current study sought to examine if the compliance vs. reliance effects reported in the literature might be moderated by individual attentional control.

In addition to PAC, we also examined the relationship between operators' SpA and their performance as well as the ways they interact with the AiTR cueing system. Chen and Terrence [1] observed that low SpA operators indicated a preference of visual cueing display over tactile display, while high SpA operators showed the opposite preference. The current study provided an opportunity to examine if this finding could be replicated. Additionally, Lathan and Tracey [10] demonstrated that people with higher SpA performed better in a teleoperation task through a maze. They finished their tasks faster and had fewer errors. Lathan and Tracey suggested that military missions can benefit from selecting personnel with higher SpA to operate robotic devices. Our previous studies also found SpA to be a good predictor of the operator's robotics and gunnery task performance [1][9][11].

2.0 METHOD

2.1 Participants

Twenty-four college students (4 females and 20 males, mean age = 22.3) participated in this study, and they were compensated $15/hr or with class credit for their participation.

2.2 Apparatus

2.2.1 Simulators

The experiment was conducted using Tactical Control Unit (TCU) developed by the U.S. Army Research Laboratory's Robotics Collaborative Technology Alliance for the robotics control tasks. The TCU is a one-person crew station from which the operator can control several simulated robotic assets, which can either perform their tasks semi-autonomously or be teleoperated. The operator switched operation modes and display modes through the use of a 19 in. touch-screen display. A joystick was used to manipulate the direction in which the robot moved when in Teleop mode. The robot simulated in our study is the eXperimental unmanned vehicle (XUV) developed by the Army Research Laboratory. The simulation program used in this study was rSAF, which is a version of OneSAF for robotics simulation. The gunnery component was implemented using an additional screen and controls to simulate the out-the-window view and line-of-sight fire capabilities. The interface consisted of a 15 in. flat panel monitor and a joystick. Participants used the joystick to rotate the sensors 360˚, zoom in and out, and engage targets. Figure 1 shows the user interface of the TCU and the gunnery station.

Figure 1: Gunnery station (right) and TCU (left).

To augment target detection in the gunnery component, visual and tactile alerts were used to cue the participant to the direction of a target as determined by the AiTR. Visually, the targets consisted of icons presented around the overhead view diagram of the participant vehicle in the lower right area of the screen. The target icon appeared in one of eight possible locations around the gunner, corresponding to 45 degree increments along a 360˚ azimuth. As the gunner rotated the view, the turret portion of the vehicle diagram moved along the eight possible orientations to allow the gunner to place his/her field of view on the cued target. Tactually, target positions relative to the gunner were presented using eight electromechanical transducers known as 'tactors.' The eight tactors were arranged equidistantly on an elasticized belt worn around the abdomen just above the navel.

The reliability level of the FAP and MP alerts was both 60%. The low reliability level was deliberately chosen to investigate if the compliance vs. reliance effects as well as the individual differences reported previously in the literature would be amplified in the high workload multitasking environment in the current study. The FAP condition consisted of ten hits (i.e., alerts when there were targets), eight FAs (i.e., alerts when there were no targets), no misses (i.e., no alerts when there were targets), and two correct rejections (CRs) (i.e., no alerts when there were no targets). The MP condition consisted of two hits, no FAs, eight misses, and ten CRs. Additionally, only hostile targets were cued, not the neutral targets. The participants were instructed to detect the neutral targets independently. The alerts (either true or false) did not occur when neutral targets appeared in the environment.

2.2.2 Communication Task Materials

The communication task was administered concurrently with the experimental scenarios. The questions included simple military-related reasoning tests and simple memory tests. The inclusion of these cognitive tasks was for simulating an environment where the gunner was communicating with fellow crew members in the vehicle. Test questions were delivered by a synthetic speech program, DECTalk®. The questions were pre-recorded by a male speaker and presented at the rate of one question every 33 seconds.

2.2.3 Questionnaires and Spatial Tests

A questionnaire about attentional control [8] was used to evaluate participants' PAC. The attentional control survey consists of 21 items and measures perceived attention focus and shifting. The scale has been shown to have good internal reliability (α = .88). In our previous studies [9], we observed a positive, although somewhat weak, relationship between attentional control survey score and some multitasking performance measures. The Cube Comparison and the Hidden Patterns tests [12] as well as the Spatial Orientation Test [13] were used to assess participants' SpA. Participants' workload was evaluated using the computer-based version of NASA-TLX questionnaire [14]. A usability questionnaire was used to assess participants' reliance on tactile and/or visual cueing for the gunnery task. Participants rated their preference on a 5-point scale (from 1 to 5: entirely visual- predominately visual- both visual & tactile- predominately tactile- entirely tactile). Participants were also asked to evaluate their trust in the AiTR system using a modified survey by Jian Bisantz, and Drury [15].

2.2.4 Experimental Design

The overall design of the study is a 2 x 3 mixed design. The between-subject variable is AiTR type (FAP vs. MP). The within-subject variable is Robotics Task type (Monitor vs. Auto vs. Teleop) (see Procedure).

2.3 Procedure

After the informed consent process, participants were administered the attentional control survey and the spatial tests. After these tests, participants received training, which was self-paced and was delivered by PowerPoint® slides showing the elements of the TCU, steps for completing various tasks, and exercises for performing the robotic control tasks. After the tutorial on TCU, participants were trained on the gunnery tasks. The entire training session lasted about 2.5 hr.

In the experimental trials, participants' tasks were to use their robot to locate hostile targets in the remote environment and also find targets in their immediate environment. The tank was simulated as traveling along a designated route, which was approximately 4.3 km and lasted about 15 min. There were 10 hostile and 10 neutral targets along the route in each gunnery scenario. Hostile targets were enemy soldiers dressed in military uniform and carrying a gun; neutral targets were civilians dressed in typical Middle Eastern attire without any weapons. Participants were instructed to engage the hostile targets and verbally report spotting the neutral targets. In total, there were three 15-min scenarios, corresponding to the three robotics tasking conditions, the order of which was counterbalanced across participants.

There were three types of robotics tasks: Monitor, Auto, and Teleop. The Monitor task required the operator to continuously monitor the video feed as the robot traveled autonomously and verbally report detection of targets. There were 20 targets (5 hostile and 15 neutral) along the route. The Auto control task required the operator to monitor the video feed as the robot traveled autonomously, examine still images generated from the reconnaissance scans, and detect targets. The Teleop task required the operator to manually drive the robot (using a joystick) along a predetermined route and detect targets. For both the Auto and Teleop tasks, there were 2 to 4 targets (1 hostile plus 1 to 3 neutral targets) at each checkpoint. There were 5 checkpoints along the designated route. Upon detecting a target, participants needed to place the target on the map, label the target, and then send a spot report.

While the participants were performing their gunnery and robotics control tasks, they simultaneously performed the communication task by answering questions delivered to them via DECtalk®. There were

2-min breaks between experimental scenarios. Participants assessed their workload using the NASA-TLX after each scenario. They also evaluated their perceived utility of and trust in the AiTR at the end of the experiment. The entire experimental session lasted about 1 hr.

The dependent measures include mission performance (i.e. number of targets detected in the remote environment using the robot and number of hostile/neutral targets detected in the immediate environment), communication task performance, and perceived workload.

3.0 RESULTS

3.1 Gunnery Task Performance

A mixed analysis of variance (ANOVA) was performed to examine the effects of the concurrent robotic control tasks on the gunnery task performance (percentage of hostile targets detected), with the AiTR condition (FAP vs. MP) being the between-subject factor and the Robotics Task condition (Monitor vs. Auto vs. Teleop) as the within-subject factor. The analysis revealed that Robotics condition significantly affected number of targets detected, $F(2, 15) = 4.6$, $p < .05$ (Fig 2). Post hoc (least significant difference [LSD]) tests showed that target detection in the Monitor condition was significantly higher than in the Auto and Teleop conditions.

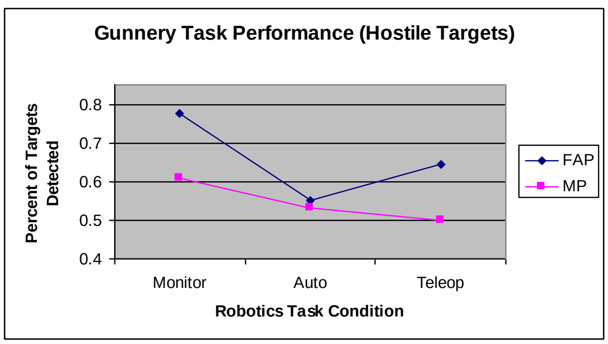

Figure 2: Gunner's target detection performance (hostile targets).

Participants were classified as high or low SpA based on their composite scores of the spatial tests (median split). Participants with higher SpA had significantly higher gunnery task performance than did those with lower SpA, $F(1, 16) = 6.3$, $p < .05$. Participants were classified as high or low PAC based on their attentional control survey scores (median split). There was also a significant AiTR x PAC interaction, $F(1, 16) = 7.4$, $p < .05$ (Fig 3, upper left). Those with lower PAC performed better with the FAP cueing, whereas those with higher PAC performed at a similar level regardless of the AiTR conditions.

In order to further examine the effect of task load on reliance of AiTR, the data of the MP condition were analyzed separately. Due to the small sample size (N = 12), no significant differences were found between those with high vs. low PAC, $F(1, 10) = 1.4$, $p > .05$. However, the trend was evident that, while those with high PAC maintained a fairly stable level of reliance throughout the experimental conditions, those with low PAC became increasingly reliant on the AiTR, as task load became heavier (i.e., Teleop > Auto > Monitor, based on Chen and Joyner [9]) (Fig 4). For the low PAC participants, the difference between the Monitor and Teleop conditions was statistically significant, $F(1, 6) = 7.1$, $p < .05$.

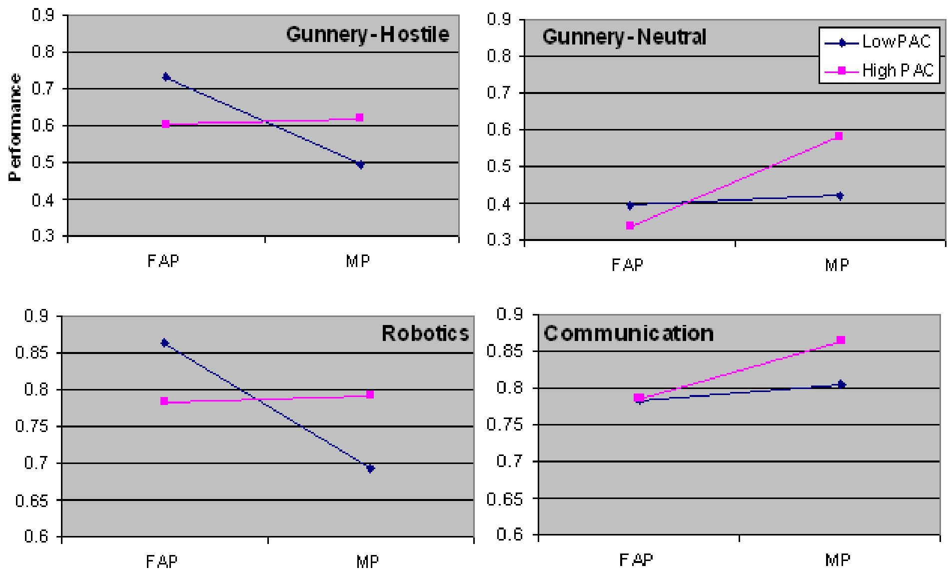

Figure 3: Interaction between PAC and AiTR unreliability.

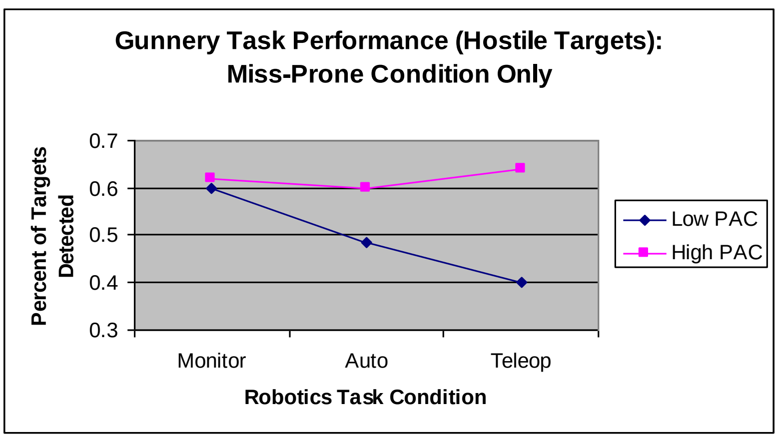

Figure 4: Effects of PAC on gunnery task performance (Miss-prone condition).

Participants' detection of neutral targets was also assessed. Since the AiTR only alerted the participants when hostile targets were present, the neutral target detection could be used to indicate how much visual attention was devoted to the gunnery station. A mixed ANOVA revealed a significant main effect for Robotics, $F(2,15) = 4.4$, $p < .05$. Post hoc tests (LSD) showed that neutral target detection in the Teleop condition was significantly lower than in the Auto condition. The main effect for AiTR failed to reach statistical significance, $F(1, 22) = 3.3$, $p > .05$. There was a significant AiTR x PAC interaction, $F(1, 16) = 3.6$, $p < .05$ (Fig 3, upper right). Those with lower PAC performed at about the same level, regardless of the AiTR type, while those with higher PAC had a better performance with the MP cueing than with the FAP cueing.

3.2 Robotics Task Performance

A mixed ANOVA revealed that there was a significant main effect for Robotics, $F(2,15) = 25.4$, $p < .001$. The Monitor condition was significantly higher than both the Auto and the Teleop conditions, in terms of percentage of targets detected. The main effect for AiTR was not significant, $p > .05$. There was a significant Robotics x AiTR interaction, $F(2,32) = 4.0$, $p < .05$. The Monitor task performance stayed at the same level regardless of the AiTR types. The Auto task performance was slightly higher with the MP cueing (although the difference failed to reach statistical significance), while the Teleop task performance was significantly higher with the FAP cueing ($p < .05$). There was also a significant AiTR x PAC interaction, $F(1,16) = 4.8$, $p < .05$ (Fig 3, lower left). Those with lower PAC had a better performance with the FAP cueing, while those with higher PAC performed better with the MP cueing.

3.3 Communication Task Performance

A mixed ANOVA revealed that there was a significant main effect for Robotics, $F(2,44) = 3.2$, $p < .05$. Monitor was significantly higher than Teleop, $F(1,22) = 5.5$, $p < .05$. Neither the main effect for AiTR nor the Robotics x AiTR interaction was significant (Fig 3, lower right).

3.4 Operator Perceived Workload

Participants' self-assessment of workload (weighted ratings of the scales of the NASA-TLX) was significantly affected by Robotic condition, $F(2,15) = 25.1$, $p < .001$. The perceived workload was significantly higher in the Teleop condition ($M = 77.7$) than in Auto ($M = 69.6$) and Monitor ($M = 61.1$). The difference between Auto and Monitor was also significant. The main effect for AiTR was not significant, $p > .05$. There was a significant Robotics x AiTR interaction, $F(2,15) = 5.5$, $p < .05$.

3.5 AiTR Display Usability Assessment

Following their interaction with the AiTR systems, 41% of participants responded that they relied predominantly or entirely on the tactile AiTR display, while 36% responded that they relied predominantly or entirely on the visual AiTR display. AiTR preference was also significantly correlated with SpA (composite spatial test scores) ($r = .51$, $p < .01$). Those with higher SpA tended to prefer tactile cueing over visual cueing. Conversely, those with lower SpA favored visual cueing over tactile cueing. We also evaluated participants' self-assessed trust in the AiTR system and compared those with higher and lower PAC. There was no significant difference between these two groups, $p > .05$.

4.0 DISCUSSION

In this study, we simulated a military tank environment and examined the performance and workload of the combined position of gunner and robotics operator. More specifically, we investigated the effects of AiTR with imperfect reliability (FAP vs. MP) on operator's performance of the automated (i.e., gunnery) task as well as the concurrent tasks (i.e., robotics and communication). Our results showed that the operator's gunnery task performance in detecting hostile targets was significantly better in the Monitor condition than in the other two robotics task conditions, consistent with the findings of Chen and Joyner [9]. In both Chen and Joyner [9] and the current study, the workload associated with the Monitor condition was significantly lower than the other robotics conditions. These results suggest that the operator had more visual and mental resources for the gunnery task when the robotics task was simply monitoring the video feed, compared with the other two robotics conditions.

Also consistent with the previous findings [1][9], participants' SpA was found to be an accurate predictor of their gunnery performance. Thomas and Wickens [16] showed that there were individual differences in scanning effectiveness and its associated target detection performance. However, Thomas and Wickens did not examine the characteristics of those participants who had more effective scanning strategies. The findings of the current study along with the previous two studies indicate that SpA may be an important factor for determining scanning effectiveness.

Our results also showed that there was a significant interaction between types of unreliable AiTR and participants' PAC. Taking the three main performance measures together (i.e., Gunnery- Hostile, Gunnery-Neutral, and Robotics), it appears that overall, for high PAC participants, FAP alerts were more detrimental than MP alerts. FAP alerts not only affected their automated task but also the concurrent task. This finding is consistent with the conclusion of Dixon, Wickens, and McCarley [3] that FAP degraded overall performance more than MP automation. However, it is worth noting that for low PAC participants, we observed the opposite pattern: MP automation was more harmful than FAP automation. Based on Figure 3, it is evident that high PAC participants did not comply with alerts in the FAP condition. Since the FAP AiTR had a 0% miss rate, a full compliance should result in a detection rate over 84%, as reported in Chen and Terrence [1] (in which a perfectly reliable AiTR was used). As predicted, Figure 3 shows that in MP conditions, high PAC participants did not rely on the AiTR and detected more targets than were cued. However, an examination of the data for the low PAC participants revealed a completely opposite trend. Specifically, with the FAP condition, low PAC participants showed a strong compliance with the alerts, which resulted in a good performance in target detection (at a similar level as in Chen & Terrence [1]). With the MP condition, however, low PAC participants evidently overly relied on the automation and therefore had a very poor performance. Indeed, Figure 4 shows that as task load became heavier, those with low PAC became increasingly reliant on the AiTR, while those with high PAC maintained a fairly stable level of reliance throughout the experimental conditions. According to Biros, Daly, and Gunsch, [17], higher task loads tend to induce a higher level of reliance on automated systems. Our present data suggest that this heightened level of reliance is also moderated by PAC. More specifically, only those with low PAC tend to exhibit over-reliance on automation (i.e., complacency) under a heavy task load.

The overall data suggest that low PAC participants had a higher trust in the automation system than did high PAC participants. It is likely that low PAC participants had more difficulty in performing multiple tasks concurrently and had to rely on automation when available. High PAC participants, in contrast, tended to rely on their own multitasking ability to perform the tasks. It is interesting to note that there was no significant difference in the participants' self-assessment of their trust in the AiTR system between high PAC and low PAC groups. This suggests that the participants' self-assessed trust in automation may not truly reflect their actual use (i.e. actual trust) of automation. Our results are consistent with past research [18][19] that self-confidence is a critical factor in moderating the effect of trust (in automation) on reliance (on the automatic system). Lee and Moray [19] found that when self-confidence exceeded trust, operators tended to use manual control. When trust exceeded self-confidence, automation was used more. Our present data suggest that, this relationship between self-confidence and level of reliance is also moderated by operator's PAC.

Participants' communication task performance was significantly better when their robotics task was Monitor than when it was Teleop. This finding is consistent with Chen and Joyner [1]. Participants' perceived workload was found to be affected by the type of concurrent robotics task. The workload was significantly higher in the Teleop condition than in the Auto condition, which in turn was significantly higher than in the Monitor condition. These results are consistent with Mitchell's [20] analysis and with the findings of Chen and Joyner [9], Chen and Terrence [1], and Schipani [21], which evaluated robotics operator workload in a field setting.

The significant positive correlation of AiTR preference with SpA indicated that as AiTR ratings tended toward considerable reliance on the tactile display, there was a concurrent shift with higher SpA. This confirmed a trend that was first observed in Chen and Terrence [1]. Perhaps those with higher SpA can more easily employ the spatial tactile signals in the dual task setting and therefore have a stronger preference for something that makes the gunner task easier to complete. Individuals with lower SpA, on the other hand, may have not utilized the spatial tactile cues to their full extent and therefore continued to prefer the visual AiTR display. According to Kozhevnikov, Hegarty, and Mayer [22], visualizers with lower SpA tend to rely on iconic imagery while those with higher SpA tend to prefer using spatial-schematic imagery while solving problems. Therefore, it is likely that in our study, those who preferred visual AiTR displays might be more iconic in their mental representations. However, this preference may have caused degraded target detection performance due to more visual attention being devoted to the visual AiTR display, not to the simulated environment. In contrast, those who were more spatial relied on the directional information of the tactile display to help them with the visually demanding tasks, resulting in a more effective performance.

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